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(54) Apparatus and method for performing thin film layer thickness metrology by deforming a thin film layer into a reflective condenser.

(57) An apparatus for measuring the thickness of a layer of material, for example a semiconductor wafer, wherein the material of the layer has a property that allows radiation to be transmitted therethrough, which comprises :

means (23,70) for deforming the layer of material (24) into a reflective condenser ;

means (10) for irradiating the front surface of the deformed layer of material with monochromatic radiation, wherein the monochromatic radiation is reflected from the front and rear surfaces of the deformed layer of material having characteristics that correspond to the thickness of said layer of material ;

means (30) for receiving the reflected monochromatic radiation and for detecting the characteristics ; and

means (36) for comparing the detected characteristics of the received reflected monochromatic radiation with a set of reference characteristics that correspond to known thicknesses and for providing an output that corresponds to the thickness of the layer of material.

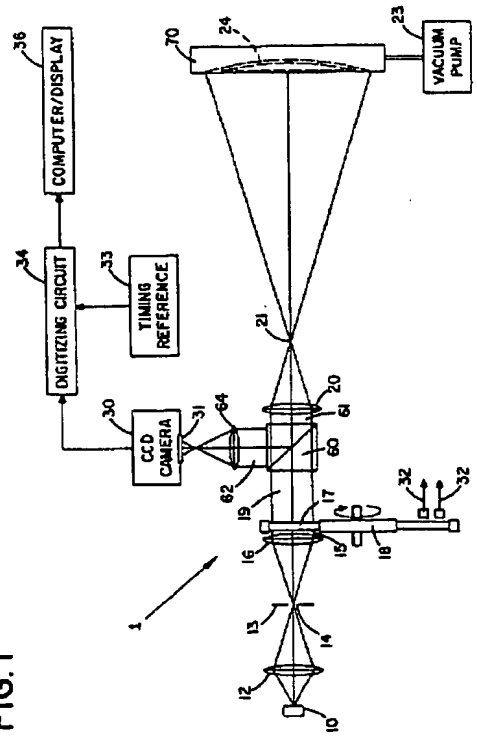

FIG. 1

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part application of U.S. Patent Application Serial No. 07/804,872, entitled, Apparatus and Method for Measuring the Thickness of Thin Films, filed on December 6, 1991, now pending and assigned to the assignee hereof.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an apparatus and method for performing thin film layer thickness metrology and, more particularly, to an apparatus and method for performing thin film layer thickness metrology on a silicon/silicon dioxide/silicon ($Si/SiO_2/Si$) structured semiconductor wafer by deforming the wafer into a reflective condenser.

Description of the PriorArt

In one particular application wherein the present invention is especially practical, a silicon-on-insulator (SOI) semiconductor wafer, typically consisting of an $Si/SiO_2/Si$ sandwich structure, is fabricated by growing a silicon dioxide (SiO_2) film on one surface of each of two silicon (Si) wafers and bonding the two silicon dioxide film surfaces together at high temperature. It should be noted that other materials, silicon nitride for example, may be used for the insulator material, and that other materials may be used for the wafer material. In such an application, an outer surface of one of the two silicon wafers in the sandwich structure is mechanically ground and polished to an average thickness of several microns. This mechanical grinding and polishing unfortunately results in large spatial variations in the thickness of this one silicon wafer, or this outer silicon layer. To reduce these spatial variations, a thickness error map that indicates thickness non-uniformities in this outer silicon layer over the entire wafer surface is required, for example, to initialize a further micropolishing process.

A sequence of measuring the spatial variations in the thickness of the outer silicon layer followed by thinning and smoothing the surface of this layer by micropolishing may need to be performed several times before the entire outer silicon layer achieves a desired thickness. In order to reduce costs and increase production, a measurement of at least 400 points on a wafer surface in 60 seconds is desirable.

Current commercial instruments, however, can typically provide a thickness measurement of a thin film layer at only a single point thereon. These instruments use a focused lens or a fiber bundle to locally illuminate a surface of the thin film layer with a beam of monochromatic light, and a grating or prism spectrograph to measure the surface spectral reflectance at each point. In all cases, this surface spectral reflectance data must be numerically corrected due to variations in the angle of incidence caused by the f-number of the illuminating beam.

Current commercial instruments may be extended to cover an entire thin film layer, such as an outer silicon layer of an SOI semiconductor wafer, by moving either the measuring instrument or the wafer in a controlled manner. However, the time required for these instruments to determine the thickness of an outer silicon layer of an SOI semiconductor wafer at a single point on the outer silicon layer is on the order of several minutes, and characterizing the entire outer silicon layer with at least 400 measurement points far exceeds the time desired for efficient wafer production. It is therefore desirable to perform thin film layer thickness metrology over an entire thin film layer, such as an entire outer silicon layer of an SOI semiconductor wafer, in an efficient, albeit an economical and highly accurate manner.

SUMMARY OF THE INVENTION

The present invention contemplates an apparatus and method for efficiently determining a thin film layer thickness of, for example, an entire thin film layer of a semiconductor wafer. Non-uniformities in the thickness of this thin film layer are obtained by measuring the reflectance characteristics over a full aperture of a surface of the wafer, and comparing this measured reflectance data to reference reflectance data by using numerical iteration or by using a calibration wafer having known thin film layer thicknesses.

To efficiently measure the reflectance characteristics over a full aperture of a semiconductor wafer surface, a filtered white light source is used to produce a series of monochromatic light beams at several different wavelengths. These monochromatic light beams are sequentially projected onto an entire surface of the wafer, resulting in coherent interactions in this light as it is reflected between physical boundaries within the wafer structure. As a result of these interactions, an interference fringe pattern would normally be formed on the

illuminated surface of the wafer for each sequentially projected beam and, consequently, for each wavelength. However, prior to projecting the monochromatic light beams onto the wafer surface, the wafer is deformed into a reflective condenser. Thus, each sequentially projected monochromatic light beam is reflected off the deformed wafer with no interference fringe pattern being formed on the illuminated surface of the wafer. However, an image of an interference fringe pattern is contained in each reflected monochromatic light beam.

Each reflected monochromatic light beam is collected by a lens system that projects each corresponding interference fringe pattern image onto, for example, a detector array of a charge coupled device (CCD) camera, where each of these images are then captured in full aperture. The interference fringe pattern images are captured by digitizing pixels in the CCD camera detector array that correspond to each projected interference fringe pattern image present. A reflectance map of the entire wafer surface is then generated from this captured interference fringe pattern image. Several reflectance maps are generated from each measured wafer to eliminate thickness ambiguities which can result from thin film layers having phase thicknesses greater than 2π.

The reference reflectance data for a wafer can be obtained by a theoretical calculation or through the use of a calibration wafer. The theoretical method consists of numerically computing reference reflectance characteristics based on assumed values for the intrinsic optical properties of the wafer materials. Alternatively, a calibration wafer, having a known thin film layer thickness profile, can be constructed from the same batch of materials used to construct the wafer to be measured. By subjecting this calibration wafer to the measuring method of the present invention, reference reflectance data is accurately obtained.

The comparison between the measured reflectance data and the reference reflectance data is performed by a computer. Upon performing this comparison, the computer provides a mapping of thin film layer thicknesses or a mapping of thin film layer thickness non-uniformities over the full aperture of the wafer.

A primary objective of the present invention is to provide an efficient means for measuring thin film layer thicknesses.

Other objects and advantages of the present invention will become apparent to those skilled in the art from the following detailed description read in conjunction with the appended claims and the drawings attached hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic representation of an on-axis semiconductor wafer thin film layer thickness measuring instrument.

Figure 2 is a perspective view of a bed-of-nails type of spherically shaped vacuum chuck.

Figure 3 is a cross-sectional view of a bed-of-nails type of spherically shaped vacuum chuck in the process of deforming a wafer.

Figure 4 is a perspective view of a porous material type of spherically shaped vacuum chuck.

Figure 5 is a cross-sectional view of a porous material type of spherically shaped vacuum chuck in the process of deforming a wafer.

Figure 6 is a greatly enlarged illustration of the various layers of a SOI semiconductor wafer.

Figure 7 is a schematic representation of an off-axis semiconductor wafer thin film layer thickness measuring instrument.

Figure 8 is a plan view of a CCD camera detector array showing a wafer image outline and several reference surface image outlines.

Figure 9 is a plan view of a SOI semiconductor calibration wafer having a stepped outer silicon layer surface.

DETAILED DESCRIPTION OF THE INVENTION

An apparatus for measuring a thin film layer thickness of a semiconductor wafer **24** is shown in Figure 1 generally indicated by the numeral **1**. For the purposes of this description, the measurement of an outer silicon layer thickness of a SOI semiconductor wafer **24** is described.

The apparatus **1** provides a spatial filtered white light source that includes a plate **13** having a circular aperture **14** that is illuminated by a halogen lamp **10** through a condensing lens **12**. Light passing through aperture **14** impinges on a collimator lens **16** to form a beam **15** of collimated light. The size of the aperture **14** determines the field angle in the collimated light sections of the apparatus **1**, and the orientation the aperture **14** is chosen to allow an aperture image to be projected onto the SOI wafer **24**. It should be noted that the condensing lens **12** may be replaced by a fiber optic light guide.

The collimated beam **15** produced by the white light source and the collimator lens **16** is spectrally filtered by a series of narrow band filters **17**, nominally of 30 to 50 Å half bandwidth. The series of filters **17** are placed

around the periphery of a rotating filter wheel assembly **18**, whereby a corresponding series of collimated monochromatic light beams **19** are produced. The wavelengths of these collimated monochromatic light beams **19** typically range from 550nm to 950nm. Locating the filter wheel assembly **18** in the path of the collimated lens **15** minimizes the spectral broadening of the filtered beam **19** caused by the field angle defined by the size of the aperture **14**. A pair of electronic signals **32** are generated by the filter wheel assembly **18** to serve as a timing reference **33** for a digitizing circuit **34**. One of these signals indicates the beginning of a filter wheel revolution, whereas the other signal indicates the beginning of each filter period. Each of the collimated monochromatic light beams **19** is directed toward an on-axis beam splitter **60** where a portion **61** of each collimated monochromatic light beam is transmitted toward a second collimator lens **20**.

The second collimator lens **20** focuses the transmitted portion **61** of each collimated monochromatic light beam to a point **21** in the focal plane of the second collimated lens **20**. This focal point **21** directly corresponds to the origin **21** of the radius of curvature of a spherically shaped vacuum chuck **70**. The spherically shaped vacuum chuck **70** serves to deform the SOI wafer **24** into a spherically shaped reflective condenser. Thus, when the deformed SOI wafer **24** is illuminated with a monochromatic light beam that is focused at the focal point **21** of the second collimator lens **20**, or the radius of curvature origin **21** of the vacuum chuck **70**, this light beam is reflected back to the folcal point **21**, or origin **21**, respectively.

The spherically shaped vacuum chuck **70** deforms the SOI wafer **24** through the use of a vacuum pump **23**. This vacuum pump **23** provides a suction to which the SOI wafer **24** adheres. Referring to Figure **2**, there is illustrated in greater detail one type of the spherically shaped vacuum chuck **70** shown in Figure **1**. This type of vacuum chuck **70** can be fabricated from aluminum or any other type of non-porous material, and has a pattern, generally indicated by numeral **72**, of raised lands **75** circumferentially surrounded by a smooth surface **74**. This raised lands pattern **72**, also known as a "bed-of nails', and the smooth surface **74** have a desired spherical curvature radius. Several peripheral vacuum ports **76** are located between the lands **75** of the pattern **72** to allow a wafer to be suctioned down onto the tops of the lands **75**. Typically a 4.0 inch diameter wafer must be deformed at its center by approximately 1.25 millimeters to create a 1 meter radius of curvature reflective condenser. Similarly, an 8.0 inch diameter wafer must be deformed by approximately 5 millimeters. Deforming an SOI wafer in such a manner does not produce significant stress in the wafer and will not cause debonding between the layers of the wafer. An outline **78** of a wafer is shown to extend outside the raised lands pattern **72** and onto the smooth surface **74** so as to ensure a secure vacuum seal. A wafer typically extends outside the raised lands pattern **72** by approximately 1 millimeter. Also shown in Figure 2, is a pair of reference alignment marks **77** and a pair of reference reflecting surfaces **79** placed on the smooth surface **74**. These references **77**, **79** provide for aiding wafer alignment and for establishing a reflectance standard, respectively, as will be explained.

Turning now to Figure 3, the spherically shaped vacuum chuck **70** is shown in the process of deforming the wafer **24**. A main vacuum port **80** provides access to the peripheral vacuum ports **76** by way of a vacuum chamber **82**. The main vacuum port **80** is connected to the vacuum pump **23** shown in Figure 1, thereby providing the suction to maintain the wafer **24** in its spherically deformed position.

The spherically shaped vacuum chuck **70** of Figures 2 and 3 can be replaced by other wafer holding means such as a spherically shaped vacuum chuck **84** made of porous material, as shown in Figures 4 and 5. This type of vacuum chuck **84** can be fabricated from ceramic or any other type of rigid porous material. A block **88** of such rigid porous material has a surface **86** with a desired spherical curvature radius. This rigid porous material block **88** is bonded to a non-porous material base **90**. As shown in Figure 5, the non-porous material base **90** maintains a vacuum port **92** that allows access to a vacuum chamber **94**. Since the rigid porous material block **88** is gas permeable, a wafer **24** placed on the surface **86** of the block **88** can be spherically deformed to the curvature radius of the block surface **86** by creating a vacuum in the vacuum chamber **94**. Such a vacuum is created when the vacuum port **92** is connected to the vacuum pump **23** shown in Figure 1.

Referring to Figure 6, a SOI semiconductor wafer **24** is shown constructed in a sandwich structure comprising a mechanically polished outer silicon layer **40**, an internal silicon dioxide (SiO_2) film **42**, and a silicon wafer substrate **44**. This sandwich structure creates three interfaces **46**, **48**, **50** from which light, incident upon the outer silicon layer **40**, may be reflected. The reflectance characteristics of these interfaces **46**, **48**, **50** are based upon the intrinsic optical and physical properties of the materials in each layer **40**, **42**, **44** of the SOI wafer **24**. These properties comprise of the absorption coefficient (α) the index of refraction (n) and the thickness (t) of the material layers **40**, **42**, **44**. For an SOI wafer, it is assumed that the absorption coefficient, (α_1), of the SiO_2 layer **42** is zero. However, in general, it is permissible that the absorption coefficient be non-zero, provided that it is known.

When the SOI wafer **24** is installed in the apparatus **1** of Figure **1** and the surface **46** of the SOI wafer **24** is illuminated with a monochromatic light beam that is focused at the vacuum chuck's radius of curvature origin **21**, and hence the SOI wafer's radius of curvature origin **21**, a series of coherent interactions occur as this

light is reflected between the three material interfaces **46, 48, 50** of the SOI wafer structure **24**. These interactions produce a wavelength dependent interference fringe pattern image that is contained in the monochromatic light beam that is reflected back to the radius of curvature origin **21**. The reflectance at any point on the wafer is determined by the multiple reflections between the three surfaces and by the magnitudes of their physical properties, $n_1,\alpha_1,t_1,n_2,\alpha_2,t_2,n_3,\alpha_3$. In the unique case of an SOI wafer structure, the substrate indices (n_3,α_3) are identical to those of the outer silicon layer indices (n_2,α_2) since both are fabricated from single crystal silicon. The wafer reflectance at any wavelength can be calculated explicitly as a function of the outer silicon layer thickness if all the other parameters are known, however, the reverse problem of computing the thickness from a single measured reflectance is ambiguous. This ambiguity is created by the fact that as the outer silicon layer thickness is increased, the measured reflectance cycles between maximum and minimum values as the phase thickness (n_2t_2) increases by multiples of $\pi/4$. This multiple values problem clearly makes the computation of the value of t_2 from a single reflectance measurement impossible. The use of multiple wavelength measurements can in principle overcome the multiple values problem, but the wavelength dependent behavior of the material properties must be very accurately known or otherwise large errors occur in the thickness computations.

An alternate approach for overcoming the multiple values problem is a statistical one, wherein measured reflectance data at several wavelengths is compared on a least squares best fit basis with a library of computed spectral data at the same wavelengths. In the case of an SOI wafer, the library of spectra is computed for all values of the outer silicon layer thickness and the selection is made by choosing that outer silicon layer thickness which minimizes the least squares best fit.

Referring again to Figure 1, the reflected monochromatic light beam containing the wavelength dependent interference fringe pattern image is collected by the second collimator lens **20** and directed toward the on-axis beam splitter **60**. The beam splitter **60** redirects a portion **62** of the now collimated monochromatic light beam **61** to a final collimator lens **64**. This final collimator lens **64** converges the redirected portion **62** of the collimated monochromatic light beam onto a CCD camera detector array **31** where the wavelength dependent interference fringe pattern image contained in the reflected monochromatic light beam is displayed. It should be noted that the filter wheel assembly **18** can alternatively be placed in the collimated beam **62** redirected by the beam splitter **60**, instead of in the collimated beam **15** generated by the collimator lens **16**, provided that the field angle can be tolerated by the narrow band filters **17**.

An apparatus **2** for providing an alternate method of displaying the wavelength dependent interference fringe pattern image on the CCD camera detector array **31** is shown in Figure 7. In this scheme, the vacuum chuck **27** can be identical to the vacuum chucks **70, 84** of Figures 2 and 3 and Figures 4 and 5, respectively, except that it has an ellipsoidally shaped surface, thereby allowing the monochromatic light beam containing the wavelength dependent interference fringe pattern image to be reflected to an off-axis mirror **26**. This mirror **26** is positioned at the origin **25** of the radius of curvature of the ellipsoidally shaped vacuum chuck **27**, which is also a point **25** in the focal plane of a final collimator lens **28**. Thus, the reflected monochromatic light beam containing the wavelength dependent interference fringe pattern image is redirected by the off-axis mirror **26** to the final collimator lens **28**. The final collimator lens **28** then projects a collimated monochromatic light beam **29** onto the CCD camera detector array **31** whereby the wavelength dependent interference fringe pattern image is displayed. It should be noted that, as before, the filter wheel assembly **18** can alternatively be placed in the collimated beam **29** provided that the field angle can be tolerated by the narrow band filters **17**. It should also be noted that in this apparatus 2 a monochromator can replace the halogen lamp **10**, the condensing lens **12**, the first two collimator lenses **16, 20**, and the narrow band filter wheel **18**, provided that the slewing rate of the monochromator between different wavelengths is sufficiently high; up to twenty different wavelengths in less than one second.

The determination of the method used to display the wavelength dependent interference fringe pattern image on the CCD camera detector array **21** is dependent upon the beam intensity that is required to maintain a suitably displayed wavelength dependent interference fringe pattern image. The use of the on-axis beam splitter method results in decreased beam intensity due to optical losses that are inherent to beam splitters. The alternate off-axis mirror method eliminates the need for a beam splitters, thereby improving the optical throughput by a factor of 4. Thus, if the wavelength dependent interference fringe pattern image is not suitably displayed using the on-axis beam splitter method, then the off-axis mirror method must be used.

Referring to Figure 8, the CCD camera detector array **31** is shown with an SOI wafer image outline **52**, a pair of reference alignment image outlines **54**, and a pair of reference reflecting image outlines **56**, projected upon its surface. These reference images **54, 56** are formed by the reference alignment marks **77** and reference reflecting surfaces **79** on the surfaces **74, 86** of the vacuum chucks **70, 84**, respectively. When illuminated with a monochromatic light beam that is focused at the vacuum chuck radius of curvature origin **21**, these references **77, 79** provide reflections from their surfaces. Similar to the SOI wafer wavelength dependent inter-

ference fringe pattern image, images of these references **77, 79** are contained in the reflected monochromatic light beam, whereby they are eventually projected onto the CCD camera detector array **31**. The reference alignment marks **77** provide aid in wafer alignment, whereas the reference reflecting surfaces **79** serve to normalize the CCD signals so that actual wafer reflectance can be calculated. As shown, the CCD detector array **31** is made up of a plurality of CCD pixels **57**.

Referring back to Figure 1, the wavelength dependent interference fringe pattern image that is displayed on the CCD camera detector array **31** is captured by the CCD camera **30**. A reflectance map is generated by digitizing the CCD pixels **57** that correspond to each displayed wavelength dependent interference fringe pattern image through the use of a digitizing circuit **34**. This raw reflectance data can be normalized to eliminate variations in CCD pixel sensitivity and can be reduced in size by averaging signals over blocks of CCD pixels **57** to match the spatial limitations of any subsequent chemical micropolishing process. In determining the thickness (t_2) of the outer silicon layer **40** of the SOI wafer **24**, either a numerical computation method or a SOI calibration wafer may be used. Both of these methods typically require the use of a computer **36**.

The numerical method of determining outer silicon layer thickness (t_2) includes assuming values for the thin film constants n_1, α_1, t_1, n_2, α_2, n_3, and α_3, and calculating spectral reflectances for a set of wavelengths corresponding to the monochromatic light produced by the filtered white light source. This calculation is done for a number of different outer silicon layer thicknesses (t_2) and, provided that the initial thin film constant assumptions are correct, should only need to be computed once. This calculation provides sets of reflectance values, $R_o(\lambda_1, \lambda_2, \ldots \lambda_m, t_2)$, for thicknesses ranging from the thinnest to the thickest estimated value of the outer silicon layer. These computed spectral reflectance are then compared with the measured reflectance data, $R_m(\lambda_1, \lambda_2, \ldots \lambda_m, t_2)$ at specific points of the wafer using a root mean square (rms) merit function of the form,

$$M(x, y, t_2) = \left[\frac{1}{nmax} \left[\sum_{n=1}^{nmax} [R_m(x, y, \lambda_n) - R_c(\lambda_n, t_2)]^2 \right] \right]^{1/2}$$

This merit function is evaluated for different values of t_2 until a minimum or best match is found, which in turn indicates the most likely thickness. Of course, other pattern matching merit functions can be used if desired.

Unknown variations in any of the assumed thin film constants may cause errors to propagate through the computation process as outer silicon layer thickness errors. Such first order error sources include the lack of knowledge of the thickness (t_1) of the SiO_2 layer **42** over the wafer aperture and the dispersive effects of the silicon index of refraction (n_1). If the value of the merit function is too large, indicating a poor match, then new computed spectral reflectances will have to be generated for a closer set of t_2 thicknesses, iterated with the absorption coefficients (α_2, α_3) and the indices of refraction (n_2, n_3) of the outer silicon layer **40** and the silicon substrate **44**, respectively, or the index of refraction (n_1) and the thickness (t_1) of the SiO_2 layer **42**.

The second method of determining outer silicon layer thickness is to generate a set of spectral reflectances from a SOI calibration wafer **58** having a stepped outer surface, as shown in Figure 9, wherein each square area **59** of the wafer has a different known outer silicon layer thickness. It is preferred that the wafer have at least 500 reference squares to cover the likely range of outer silicon layer thicknesses. This wafer **58** can be calibrated for outer silicon layer thicknesses down to zero silicon thickness by using a stylus profilometer. The calibration wafer **58** is manufactured from the same batch of materials and is subject to the same manufacturing conditions as the wafer **24** under measurement. Consequently, the intrinsic optical properties of the calibration wafer such as the absorption coefficient and the index of refraction, and also the dispersive behavior should match those of the wafer **24** being tested.

The spectral reflectances of the calibration wafer **58** are obtained by subjecting this wafer to the measuring method of the present invention. These spectral reflectances are stored in the computer **36** and are used as a reference for comparison with the spectral reflectance of a measured SOI wafer **24**. The calibration wafer **58** has reference reflectances for at least 500 different outer silicon layer thicknesses and the reference reflectance that most closely matches the reflectance at any point on the surface of the measured SOI wafer **24** indicates the outer silicon layer thickness at that point.

Although both of these methods meet the objective of providing a 400 point measurement of outer silicon layer thickness in less than 60 seconds, the calibration wafer method is potentially more accurate than the numerical approach due to the similarity of the intrinsic optical properties between the calibration wafer **58** and the SOI wafer **24** to be measured. However, the calibration wafer method would require on-line production capability to generate a new calibration wafer **58** if the basic wafer process is significantly altered.

It is thus seen that the objectives set forth above are efficiently attained and, since certain changes can

be made in the above described apparatuses and methods without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

Claims

1. An apparatus for measuring the thickness of a layer of material having front and rear surfaces, wherein said material of said layer has a property that allows radiation to be transmitted therethrough, said apparatus comprising:

   means for deforming said layer of material into a reflective condenser;

   means for irradiating said front surface of said deformed layer of material with monochromatic radiation, wherein said monochromatic radiation is reflected from said front and rear surfaces of said deformed layer of material having characteristics that correspond to the thickness of said layer of material;

   means for receiving said reflected monochromatic radiation and for detecting said characteristics; and

   means for comparing said detected characteristics of said received reflected monochromatic radiation with a set of reference characteristics that correspond to known thicknesses and for providing an output that corresponds to the thickness of said layer of material.

2. The apparatus as defined in claim 1, wherein said means for deforming comprises means for deforming the shape of said layer of material into a reflective condenser with a specific curvature, whereby said reflective condenser reflects said monochromatic radiation that irradiates said front surface of said deformed layer of material.

3. The apparatus as defined in claim 2, wherein said means for deforming comprises a spherically shaped vacuum chuck with a constant radius of curvature, whereby said spherically shaped vacuum chuck deforms said layer of material into a spherically shaped reflective condenser with said constant radius of curvature.

4. The apparatus as defined in claim 3, wherein said spherically shaped vacuum chuck is fabricated from a non-porous type of material having a pattern of raised lands therein and a plurality of peripheral vacuum ports therethrough, and wherein a vacuum suction is applied to said plurality of peripheral vacuum ports so as to deform said layer of material.

5. The apparatus as defined in claim 3, wherein said spherically shaped vacuum chuck is fabricated from a porous type of material, wherein said porous type of material is gas permeable, and wherein a vacuum suction is applied to one area of said porous material such that said layer of material adheres to another area of said porous material so as to deform said layer of material.

6. The apparatus as defined in claim 2, wherein said means for deforming comprises an ellipsoidally shaped vacuum chuck with a specific radius of curvature, whereby said ellipsoidally shaped vacuum chuck deforms said layer of material into a ellipsoidally shaped reflective condenser with said specific radius of curvature.

7. The apparatus as defined claim 6, wherein said ellipsoidally shaped vacuum chuck is fabricated from a non-porous type of material having a pattern of raised lands therein and a plurality of peripheral vacuum ports therethrough, and wherein a vacuum suction is applied to said plurality of peripheral vacuum ports so as to deform said layer of material.

8. The apparatus as defined in claim 6, wherein said ellipsoidally shaped vacuum chuck is fabricated from a porous type of material, wherein said porous type of material is gas permeable, and wherein a vacuum suction is applied to one area of said porous material such that said layer of material adheres to another area of said porous material so as to deform said layer of material.

9. The apparatus as defined in claim 1, wherein said means for irradiating comprises means for irradiating said front surface of said layer of material with visible light.

10. The apparatus as defined in claim 9, wherein said means for irradiating with visible light comprises means

for sequentially irradiating said front surface with visible monochromatic light of differing wavelengths, such that ambiguities that arise when the thickness of said layer of material is a multiple of one of said differing wavelengths are eliminated.

11. The apparatus as defined in claim 10, wherein said means for sequentially irradiating with visible monochromatic light of differing wavelengths comprises:

a white light source;

means for collimating said white light into a collimated beam;

a plurality of narrow band filters for passing different wavelengths;

means for sequentially placing said narrow band filters one at a time into said collimated beam to form a collimated monochromatic beam; and

means for focusing said collimated monochromatic beam to the radius of curvature origin of said deformed layer of material, thereby directing said focused monochromatic beam onto said front surface of said deformed layer of material.

12. The apparatus as defined in claim 11, wherein said means for sequentially placing said narrow band filters comprises a rotatable filter wheel assembly.

13. The apparatus as defined in claim 12, additionally comprising electronic sensors associated with said rotatable filter wheel assembly for providing electrical outputs indicative of each rotation of said filter wheel and a beginning of each narrow band filter period.

14. The apparatus as defined in claim 10, wherein said means for sequentially irradiating with visible monochromatic light of differing wavelengths comprises a monochromator.

15. The apparatus as defined in claim 1, wherein said means for irradiating said front surface of said layer of material with monochromatic radiation comprises:

a source of white light;

means for focusing said white light into a focused beam directed onto said front surface of said deformed layer of material; and

means for passing only one selected wavelength of monochromatic radiation at a time.

16. The apparatus as defined in claim 15, wherein said means for passing only one selected wavelength comprises a rotatable filter wheel assembly.

17. The apparatus as defined in claim 1, wherein said means for irradiating comprises a monochromator.

18. The apparatus as defined in claim 1, wherein said means for receiving said reflected radiation and for detecting said characteristics comprises a charge coupled device.

19. The apparatus as defined in claim 1, wherein said set of reference characteristics used in said means for comparing said detected characteristics is computed based on predetermined thicknesses and assumed optical properties of said material of said layer.

20. The apparatus as defined in claim 19, wherein said means for comparing includes a computer having said set of reference characteristics stored therein.

21. The apparatus as defined in claim 1, wherein said set of reference characteristics used in said means for comparing said detected characteristics is obtained by storing characteristics derived from a layer of material having a plurality of known thicknesses.

22. The apparatus as defined in claim 21, wherein said means for comparing comprises a computer having said set of reference characteristics stored therein.

23. The apparatus as defined in claim 1, wherein said layer of material is one of a plurality of thin film layers formed on a substrate.

24. The apparatus as defined in claim 23, wherein said other thin film layers have properties that allow radiation to be transmitted, wherein said substrate has a property that allows radiation to be reflected, and wherein said radiation is reflected from said front and rear surfaces of said layer of material, from front

and rear surfaces of said other thin film layers, and from a front surface of said substrate.

25. The apparatus as defined in claim 24, wherein said material of said layer to be measured comprises silicon and said substrate comprises silicon.

26. The apparatus as defined in claim 1, wherein said characteristics comprise an interference fringe pattern.

27. The apparatus as defined in claim 1, wherein said front surface of said layer of material includes a full aperture surface area of said front surface of said layer of material, wherein said means for irradiating said front surface irradiates said full aperture surface area with a single beam of monochromatic radiation, wherein said means for receiving said reflected radiation and for detecting said characteristics comprises means for receiving and detecting said characteristics from said radiation reflected from said full aperture surface area, and wherein said means for comparing provides an output that corresponds to a thickness map of said full aperture surface area.

28. The apparatus as defined in claim 27, wherein said layer of material is formed on a front surface of a wafer, wherein said wafer is deformed into a reflective condenser, and wherein said means for irradiating includes:

a source of white light;

means for spatial filtering said white light source;

means for collimating said spatial filtered white light to form a collimated beam;

means placed in said collimated beam for producing collimated monochromatic light from said white light; and

means for focusing said collimated monochromatic light to the radius of curvature origin of said deformed wafer, thereby directing said focused monochromatic light onto a full aperture surface area of said front surface of said deformed wafer.

29. The apparatus as defined in claim 28, wherein said means for receiving said reflected radiation and for detecting said characteristics comprises:

means for directing said reflected radiation from said full aperture surface area of said front surface of said deformed wafer and for generating a collimated beam; and

a charge coupled device camera positioned within said collimated beam for detecting said characteristics from said reflected radiation.

30. The apparatus as defined in claim 29, wherein said means for comparing said detected characteristics comprises:

means for digitizing an output signal of said charge coupled device camera; and

means for comparing said digitized output signal with a set of digitized signals corresponding to said reference characteristics.

31. The apparatus as defined in claim 28, wherein said means for receiving said reflected radiation and for detecting said characteristics comprises:

means for generating a collimated beam from said radiation reflected from said full aperture surface area of said deformed wafer;

a beam splitter positioned within said collimated beam for redirecting said reflected radiation;

a charge coupled device camera; and

means for focusing said redirected reflected radiation onto said charge coupled device camera.

32. The apparatus as defined in claim 31, wherein said means for comparing comprises:

means for digitizing an output signal of said charge coupled device camera;

and means for comparing said digitized output signal with a set of digitized signals corresponding to said reference characteristics.

33. The apparatus as defined in claim 28, wherein said characteristics corresponding to the thickness of said layer of material comprise an interference fringe pattern image contained in said monochromatic radiation reflected from said full aperture surface area of said front surface of said deformed wafer, and wherein said means for receiving said reflected radiation comprises a charge coupled device camera for capturing said interference fringe pattern image.

34. The apparatus as defined in claim 33, wherein said charge coupled device camera captures an interference fringe pattern image from reflected monochromatic radiation at a plurality of different wavelengths.

35. The apparatus as defined in claim 34, additionally comprising means placed along the same plane as said deformed wafer, wherein said means reflect radiation for alignment purposes and for establishing a reflectance standard.

36. The apparatus as defined in claim 35, wherein said means for comparing said detected characteristics of said received reflected monochromatic radiation comprises a calibration wafer having a layer of material formed on a front surface of said calibration wafer, wherein said layer of aterial has a plurality of different known thicknesses over said front surface, and wherein said plurality of different known thicknesses are measured and stored as said set of reference characteristics.

37. The apparatus as defined in claim 35, wherein the set of reference characteristics used in said means for comparing is computed based on predetermined thicknesses and assumed properties of said layer of material and said wafer.

38. An apparatus for measuring the thickness of a layer of material having a front and a rear surface, wherein said layer is one of a possible plurality of layers each having a front and a rear surface and formed on a front surface of a substrate, and wherein said material of said layer has properties that allow light to be transmitted therethrough, said apparatus comprising:

means for deforming said layer of material, said possible plurality of other layers, and said substrate, such that a reflective condenser is formed from said front and rear surface of said layer of material, said front and rear surfaces of said possible plurality of other layers, and said front surface of said substrate;

means for providing a beam of collimated light;

means for converting said beam of collimated light into a beam of collimated monochromatic light;

means for focusing said beam of collimated monochromatic light so as to irradiate an entire front surface of said reflective condenser, said focused monochromatic light being reflected off said front and rear surfaces of said layer of material and said front and rear surfaces of said possible plurality of other layers and said front surface of said substrate, said reflected light interacting to form an interference fringe pattern image that is contained in a reflected monochromatic light beam;

means for directing said reflected monochromatic light beam onto a detector array of a charge coupled device camera so as to display said contained interference fringe pattern image, said camera providing an output corresponding to said displayed interference fringe pattern image that has been detected by said array;

means for digitizing said output of said charge coupled device camera; and

means for receiving said digitized output of said charged coupled device camera and comparing said digitized output of said charge coupled device camera with stored reference reflectance data and providing an output corresponding to the thickness of said layer of material.

39. The apparatus as defined in claim 38, wherein said means for deforming comprises a vacuum chuck.

40. The apparatus as defined in claim 38, wherein said means for directing said reflected monochromatic light beam onto said detector array of said charge coupled device camera comprises a mirror and a collimating lens.

41. The apparatus as defined in claim 38, wherein said reflected monochromatic light beam returns through said means for focusing said beam of collimated monochromatic light, wherein said means for directing said reflected monochromatic light beam onto a detector array of a change coupled device camera comprises a beam splitter and a focusing lens, and wherein said beam splitter is positioned within said beam of collimated monochromatic light.

42. A method for measuring the thickness of a layer of material, said method comprising the steps of:

providing a layer of material having front and rear surfaces, said material of said layer having properties that allow radiation to be transmitted therethrough;

deforming said layer of material into a reflective condenser;

irradiating said front surface of said deformed layer of material with monochromatic radiation, wherein said monochromatic radiation is reflected from said front and rear surfaces of said deformed layer

of material having characteristics corresponding to the thickness of said layer of material;

receiving said reflected radiation;

detecting said characteristics of said received reflected radiation;

comparing said detected characteristics of said received reflected radiation with a set of reference characteristics corresponding to known thicknesses; and

providing an output corresponding to the thickness of said layer of material based on said comparison of said detected characteristics with said set of reference characteristics.

43. The method as defined in claim 42, wherein said step of deforming said layer of material comprises the step of deforming said layer of material into a spherically shaped reflective condenser by a spherically shaped vacuum chuck, such that monochromatic radiation irradiating said front surface of said reflective condenser is reflected on-axis to be received.

44. The method as defined in claim 42, wherein said step of deforming said layer of material comprises the step of deforming said layer of material into an ellipsoidally shaped reflective condenser by an ellipsoidally shaped vacuum chuck, such that said monochromatic radiation irradiating said front surface of said reflective condenser is reflected off-axis to be received.

45. The method as defined in claim 42, wherein said step of irradiating comprises the step of sequentially irradiating said front surface with monochromatic radiation of differing wavelengths, such that ambiguities, arising when the thickness of said layer of material is a multiple of one of said differing wavelengths, are eliminated.

46. The method as defined in claim 45, wherein said step of irradiating includes the steps of:

generating a white light;

forming a collimated beam of said white light; and

filtering said collimated white light beam to generate collimated monochromatic light beams of differing narrow band wavelengths.

47. The method as defined in claim 42, additionally comprising the step of computing said set of reference characteristics based on predetermined thicknesses and assumed optical properties of said layer of material, and storing said set of reference characteristics.

48. The method as defined in claim 42, additionally comprising the steps of:

providing a reference layer of material having areas of known thickness;

measuring said thickness characteristics of said reference layer of material in said areas known thickness; and

storing said measured thickness characteristics as said set of reference characteristics.

49. The method as defined in claim 42, wherein said step of irradiating includes the step of simultaneously irradiating the entire front surface of said deformed layer of material with a single beam of monochromatic radiation, and wherein said step of providing an output comprises the step of providing an output corresponding to a thickness map of said entire front surface of said layer of material.

50. The method as defined in claim 42, wherein said step of detecting said characteristics comprises detecting said characteristics using a charge coupled device camera, wherein said camera provides output signals that correspond to said characteristics, and wherein said method includes the additional steps of:

digitizing said output signals provided by said charge coupled device camera; and

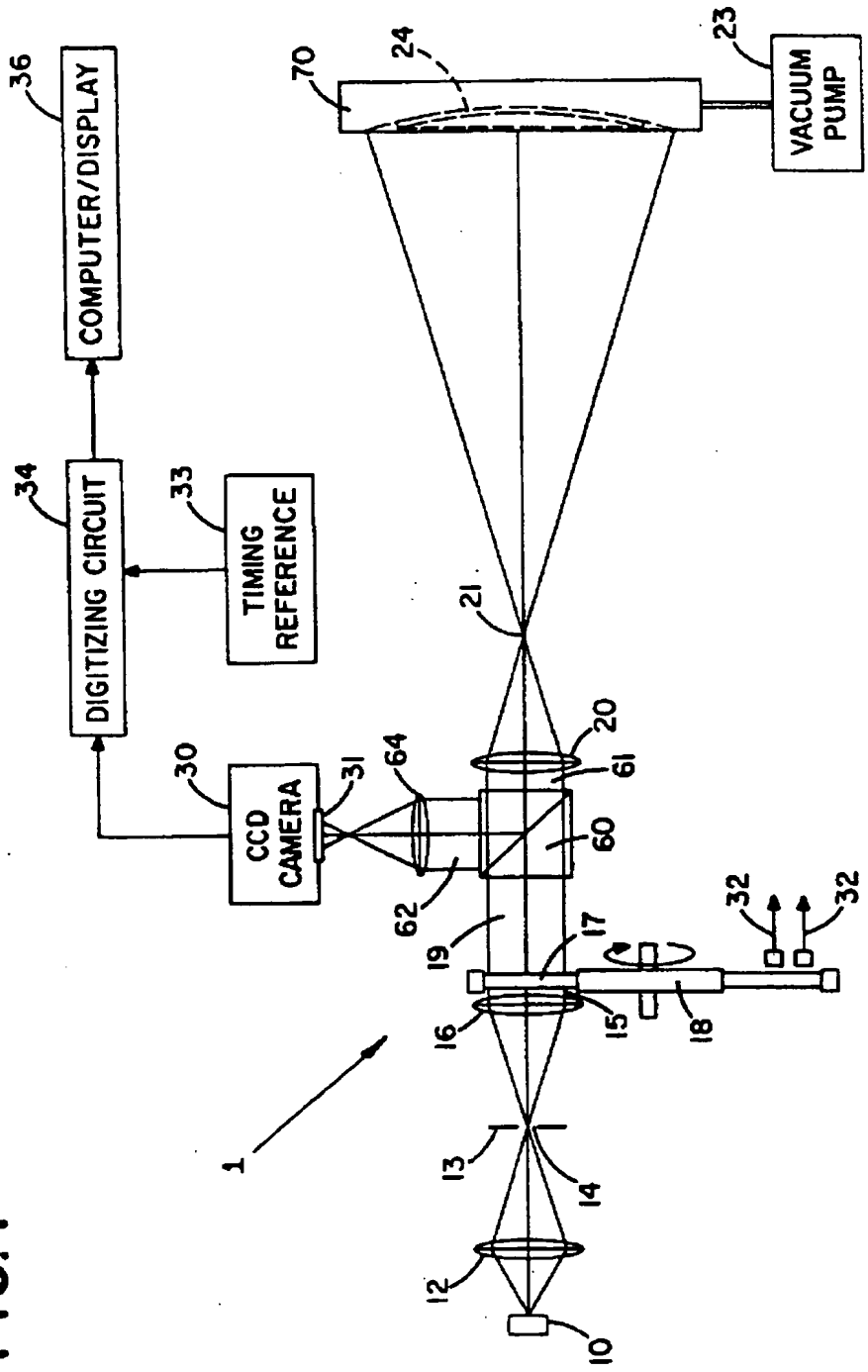
comparing said digitized output signals with a set of digitized reference signals that correspond to said set of reference characteristics.

51. The method as defined in claim 50, wherein said detected characteristics is an interference fringe pattern image produced by coherent interactions in said monochromatic radiation as it is reflected within said deformed layer of material, wherein said interference fringe pattern image is contained in said reflected radiation, and wherein said charge coupled device camera measures said interference fringe pattern image at a plurality of different points to determine the thickness of said layer of material at said plurality of different points.

52. The method as defined in claim 42, additionally comprising the steps of:

performing a chemical micropolishing process upon said front surface of said layer of material in accordance with said output corresponding to the thickness of said layer of material; and

repeating the above mentioned steps sequentially until the thickness of said layer of material corresponds to a predetermined thickness.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DIGITIZING CIRCUIT
TIMING REFERENCE
CCD CAMERA
VACUUM PUMP
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FIG. 1

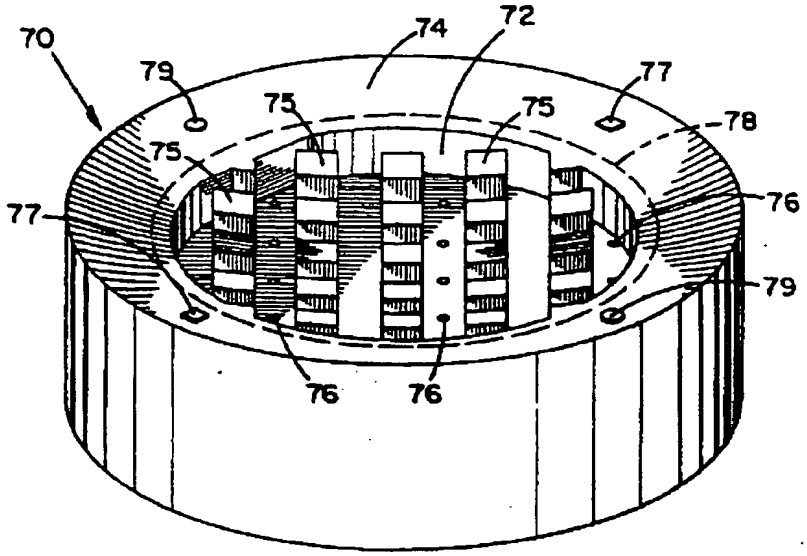
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FIG. 2

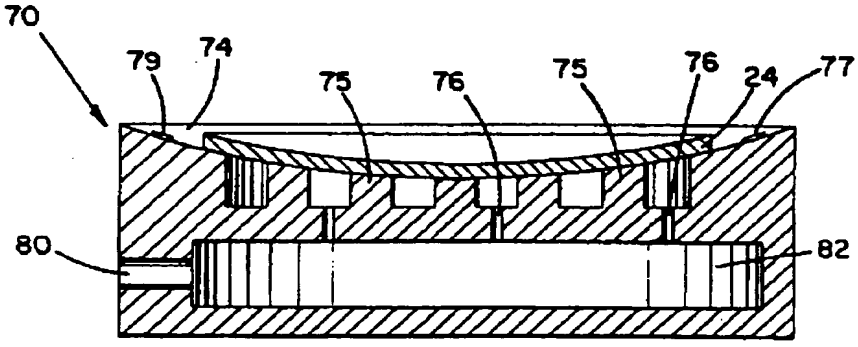
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FIG. 3

FIG. 4

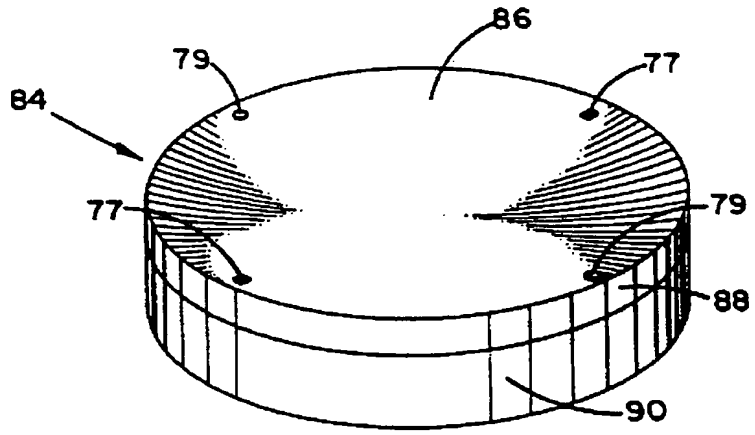


FIG. 5

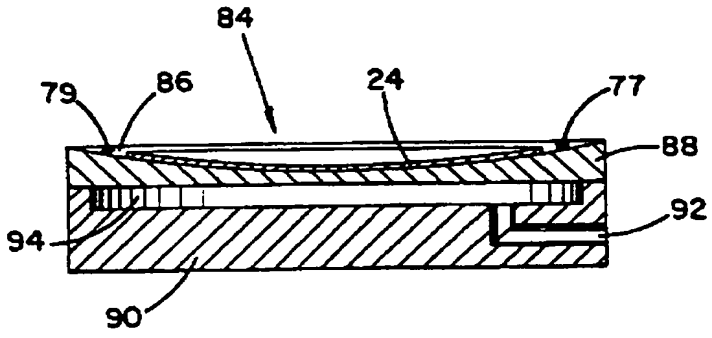
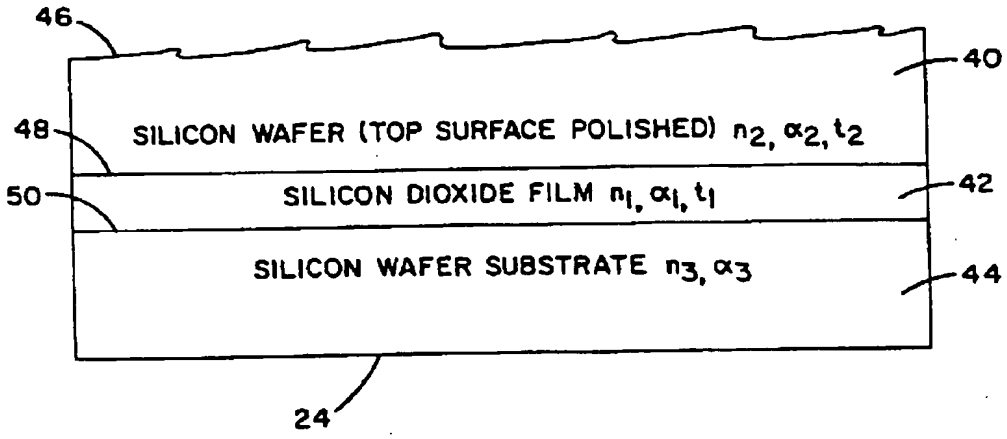


FIG. 6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SILICON WAFER SUBSTRATE n_3, α_3
44
24

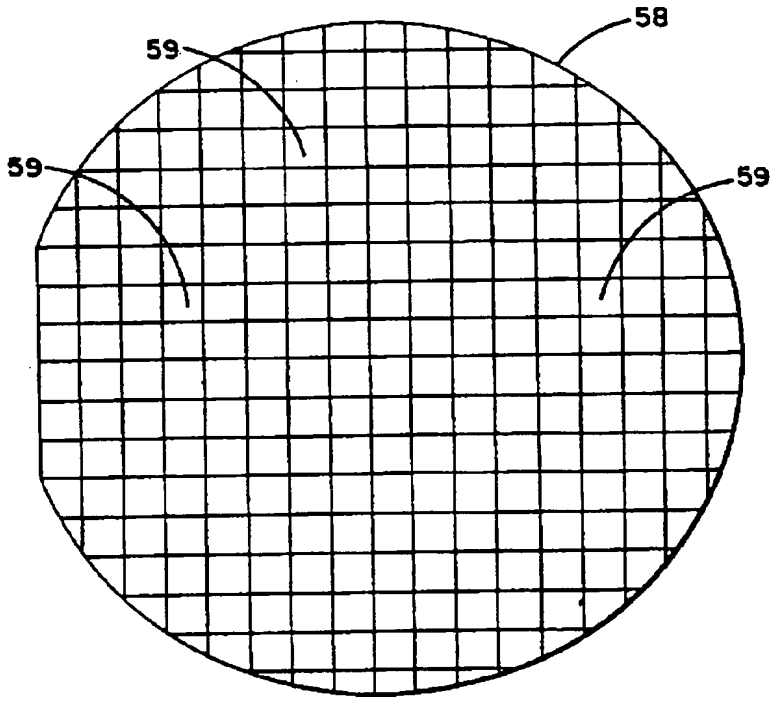
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FIG. 9

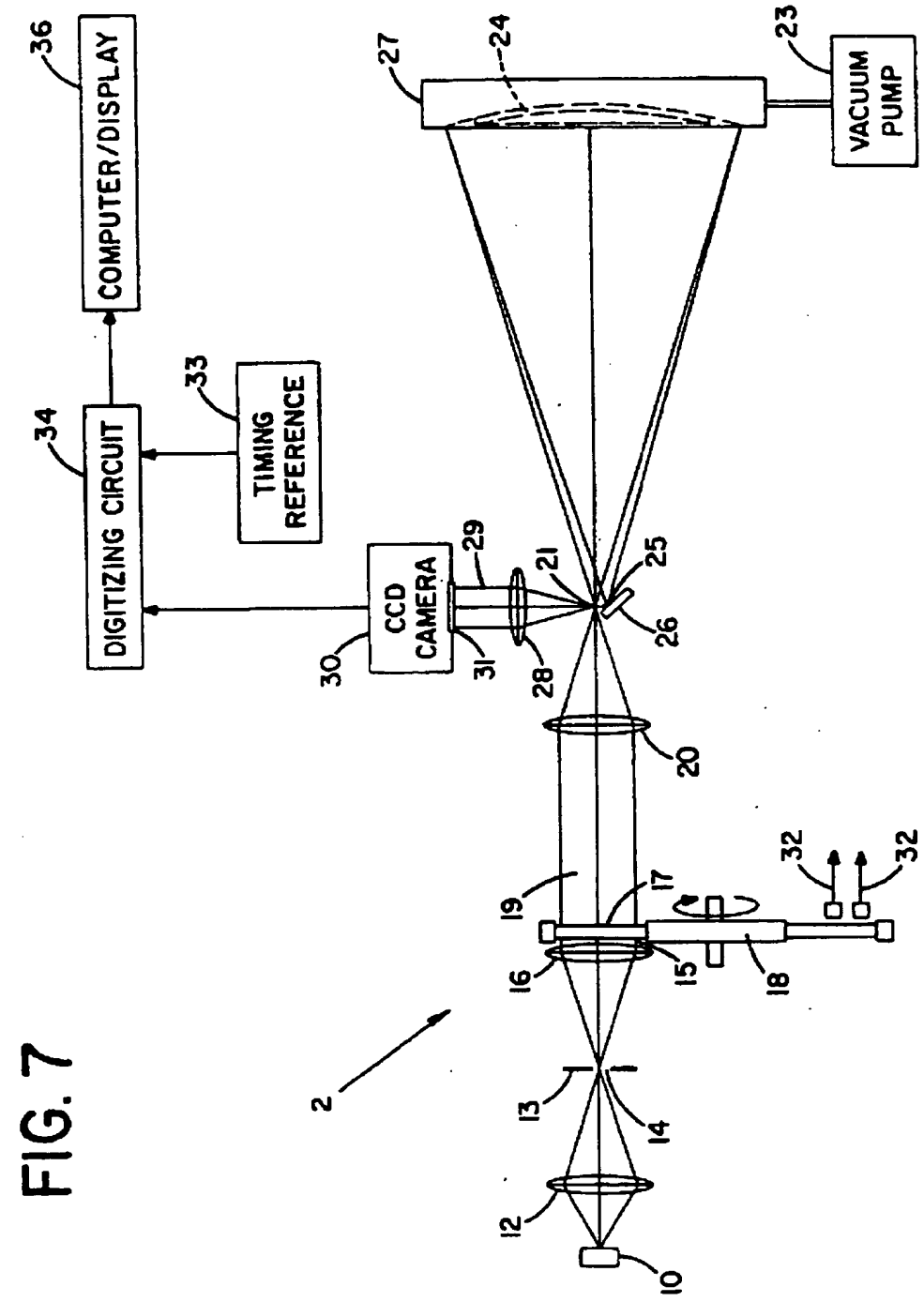
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FIG. 7
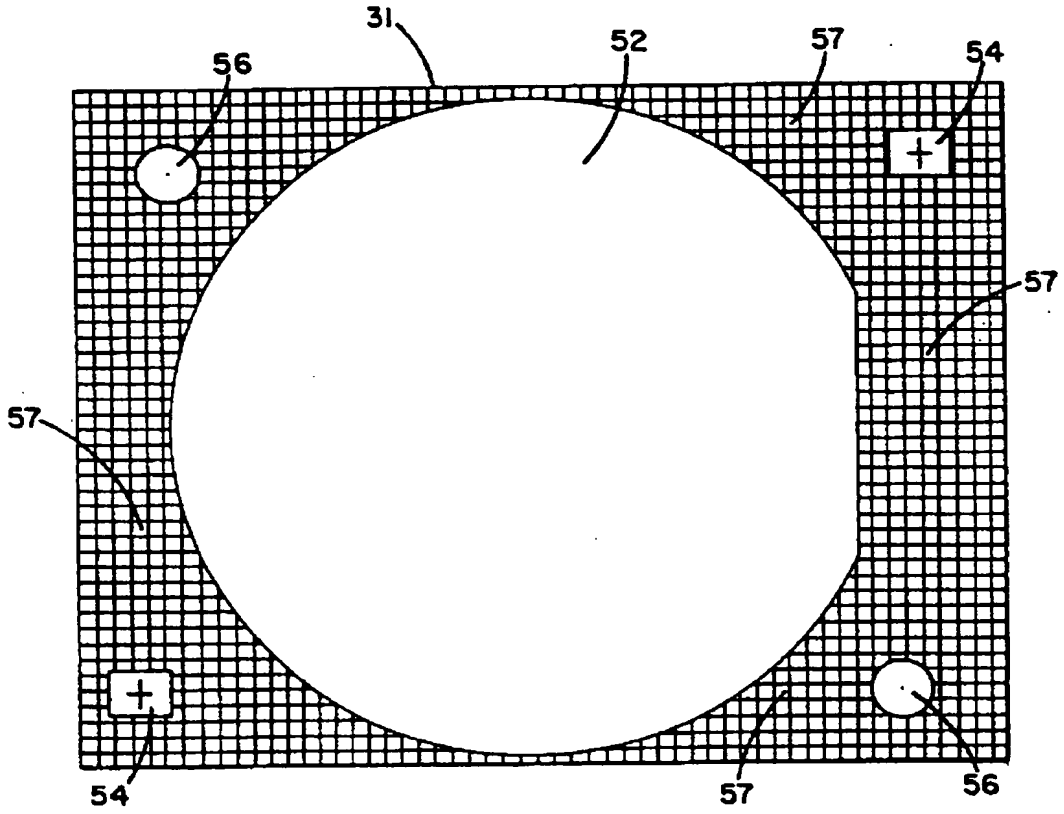
FIG. 8